



Nb-Ti magnets in WP3

E. Todesco, P. Ferracin, J. Carlos Perez, A Foussat, A. Musso, G. Kirby (CERN), T. Nakamoto (KEK) P. Fabricatore (INFN) M. Statera M. Sorbi (INFN), F. Toral (CIEMAT), H. Felice (CEA) (WP3 Nb-Ti management)

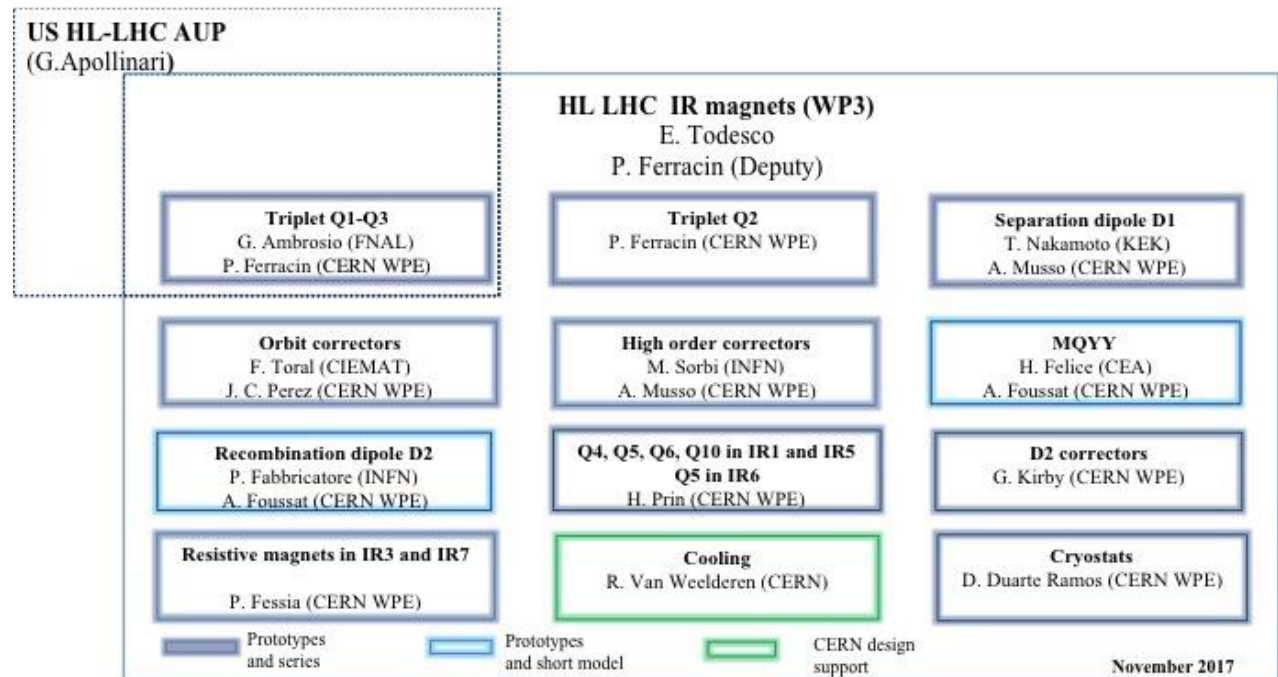
... and all the numerous colleagues



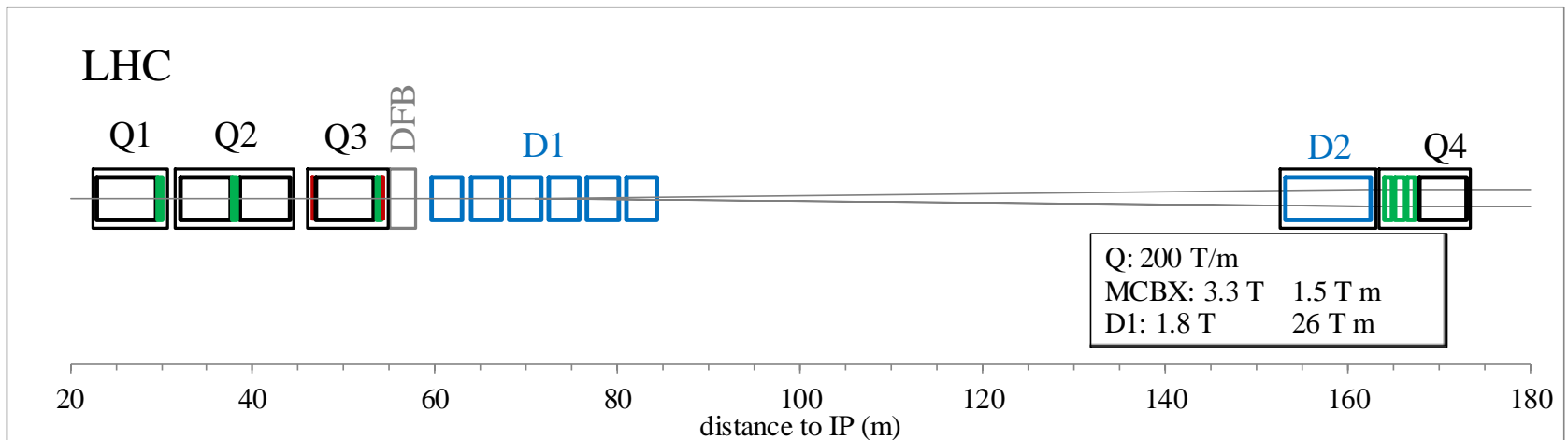
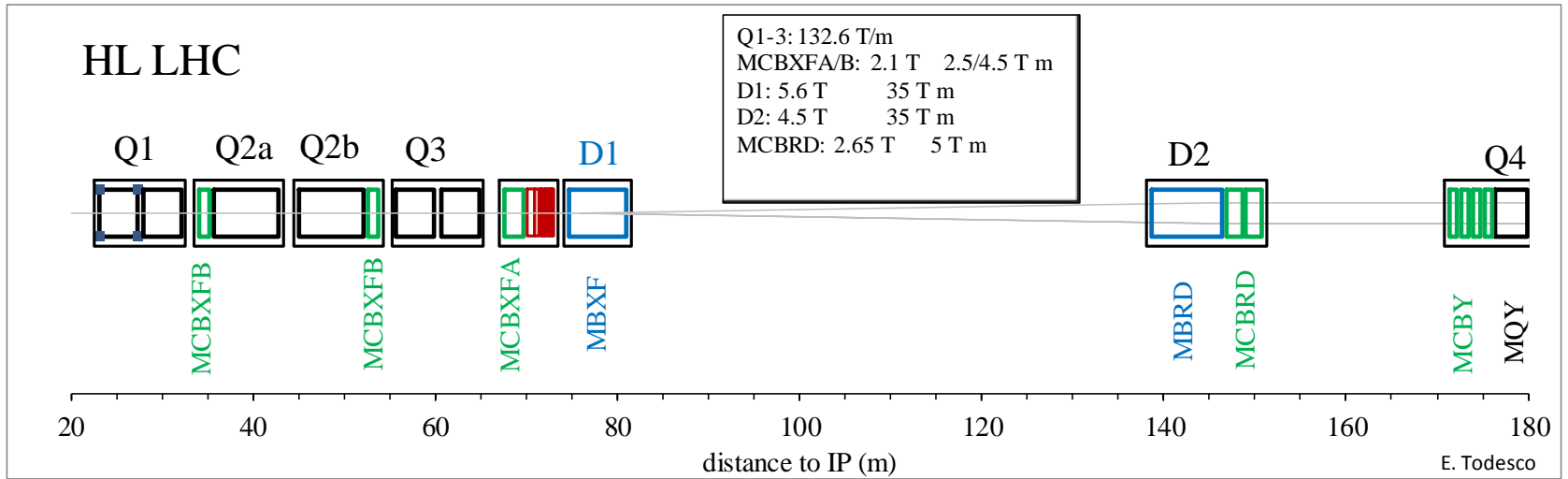
14 September 2017 - Geneve

SUMMARY

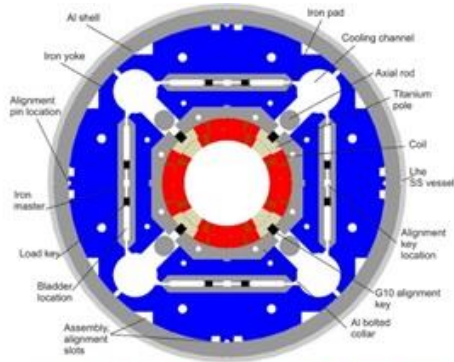
- Overview of magnets and tests
- Focus on Nb-Ti magnets not discussed in plenary talks
 - High order correctors
 - Recombination dipole (D2)
 - Canted corrector (D2 orbit corrector)
 - MQYY



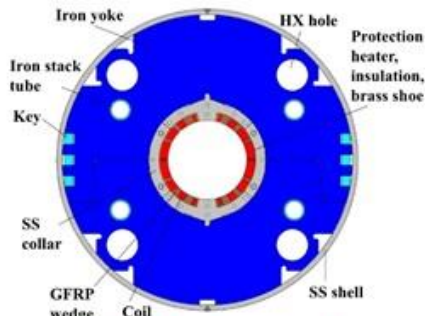
LAY OUT RECALL



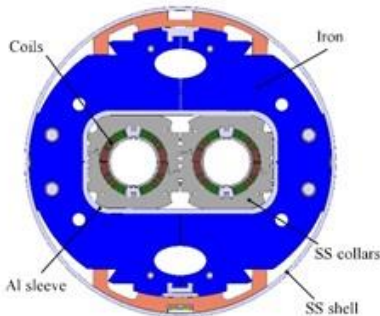
THE MAGNET ZOO



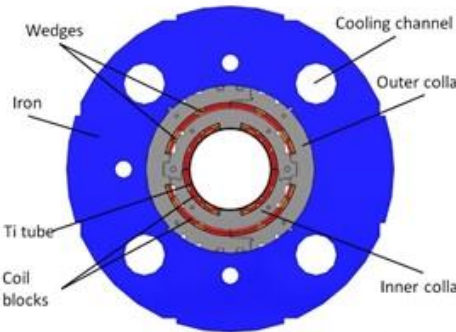
Triplet [G. Ambrosio, P. Ferracin et al.]



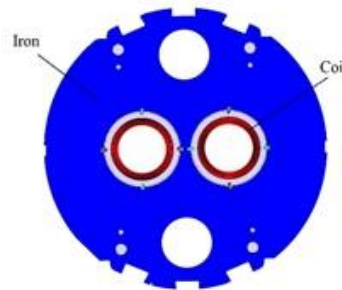
D1 [T. Nakamoto, et al.]



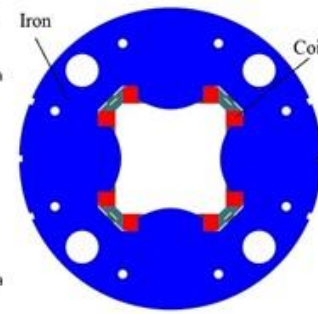
D2 [P. Fabbriatore, S. Farinon, et al.]



MCBXF [F. Toral, et al.]

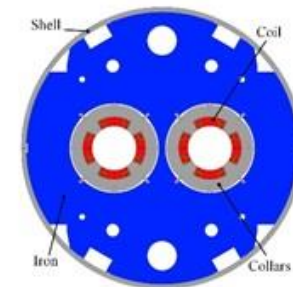


D2 correctors [G. Kirby]

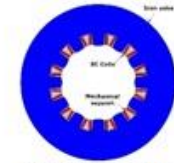


Skew quad

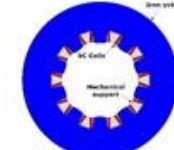
[M. Sorbi, M. Statera, et al.]



MQYY [H. Felice, et al.]



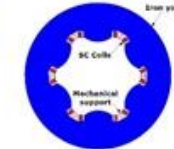
Dodecapole



Decapole

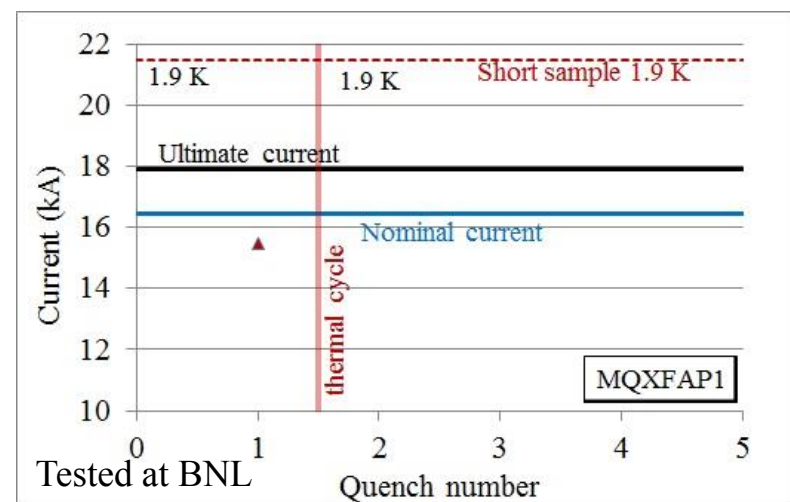
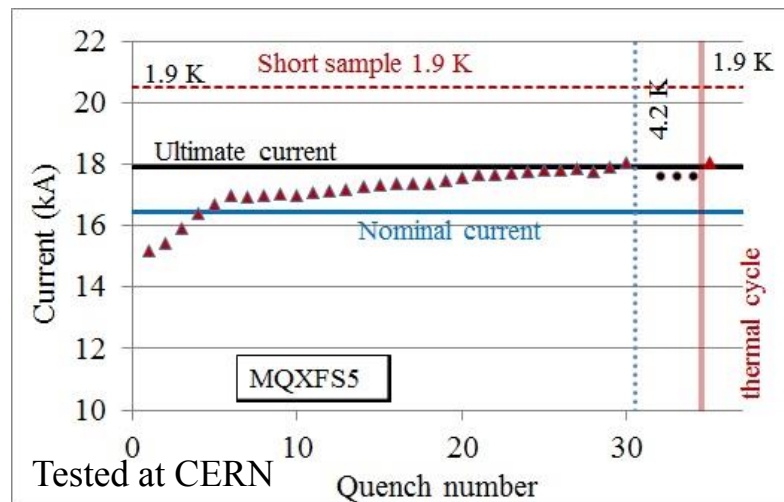
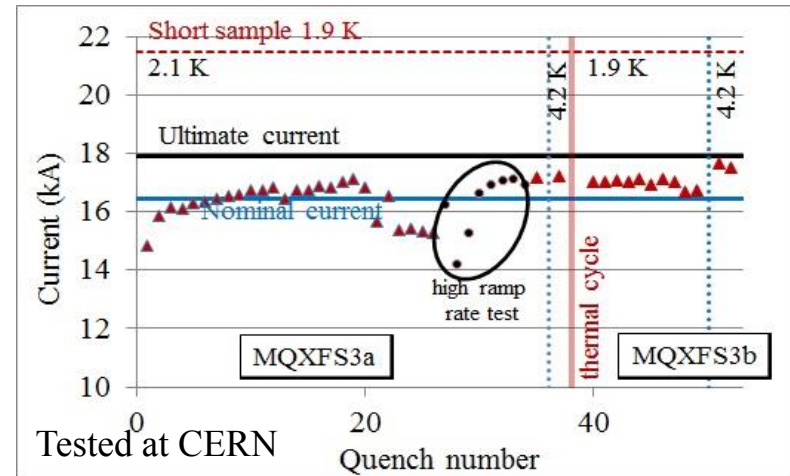
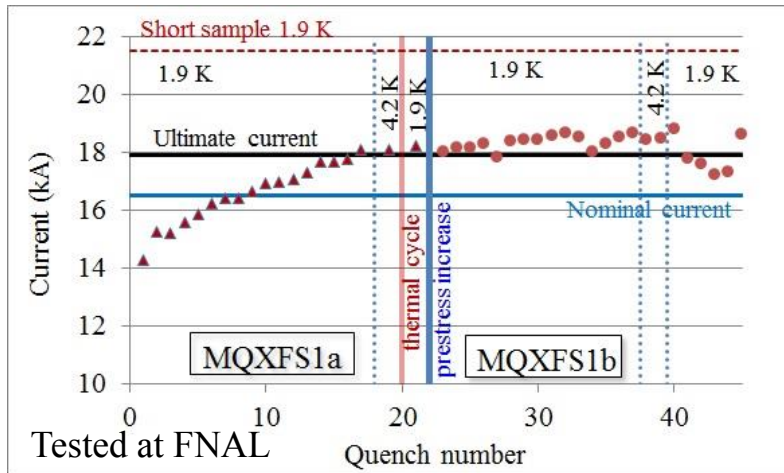


Octupole



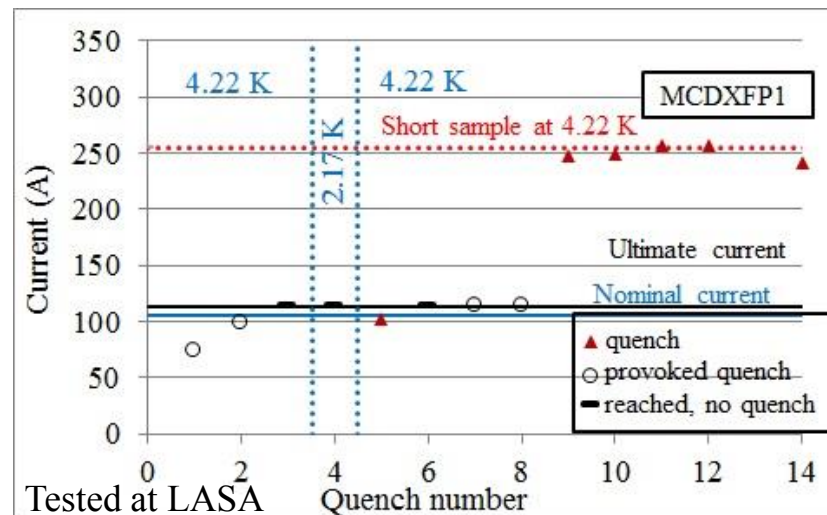
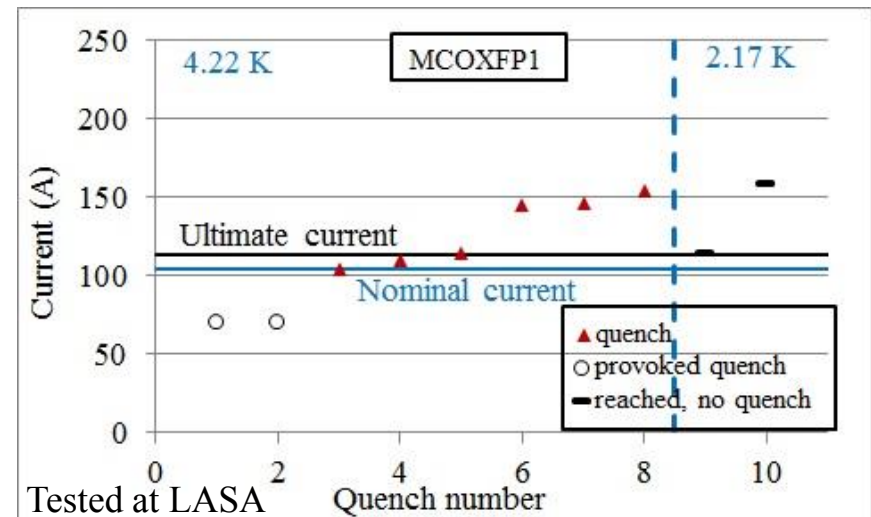
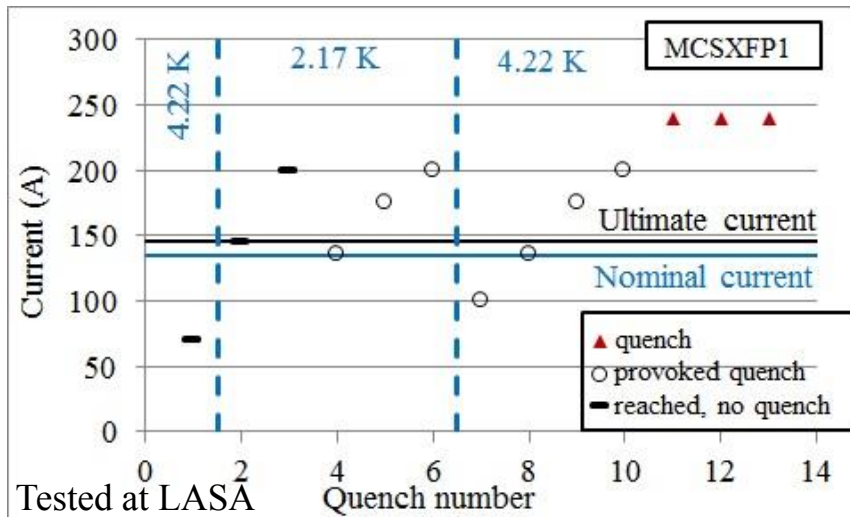
STATUS OF TESTS

- MQXF: three short models tested, one prototype



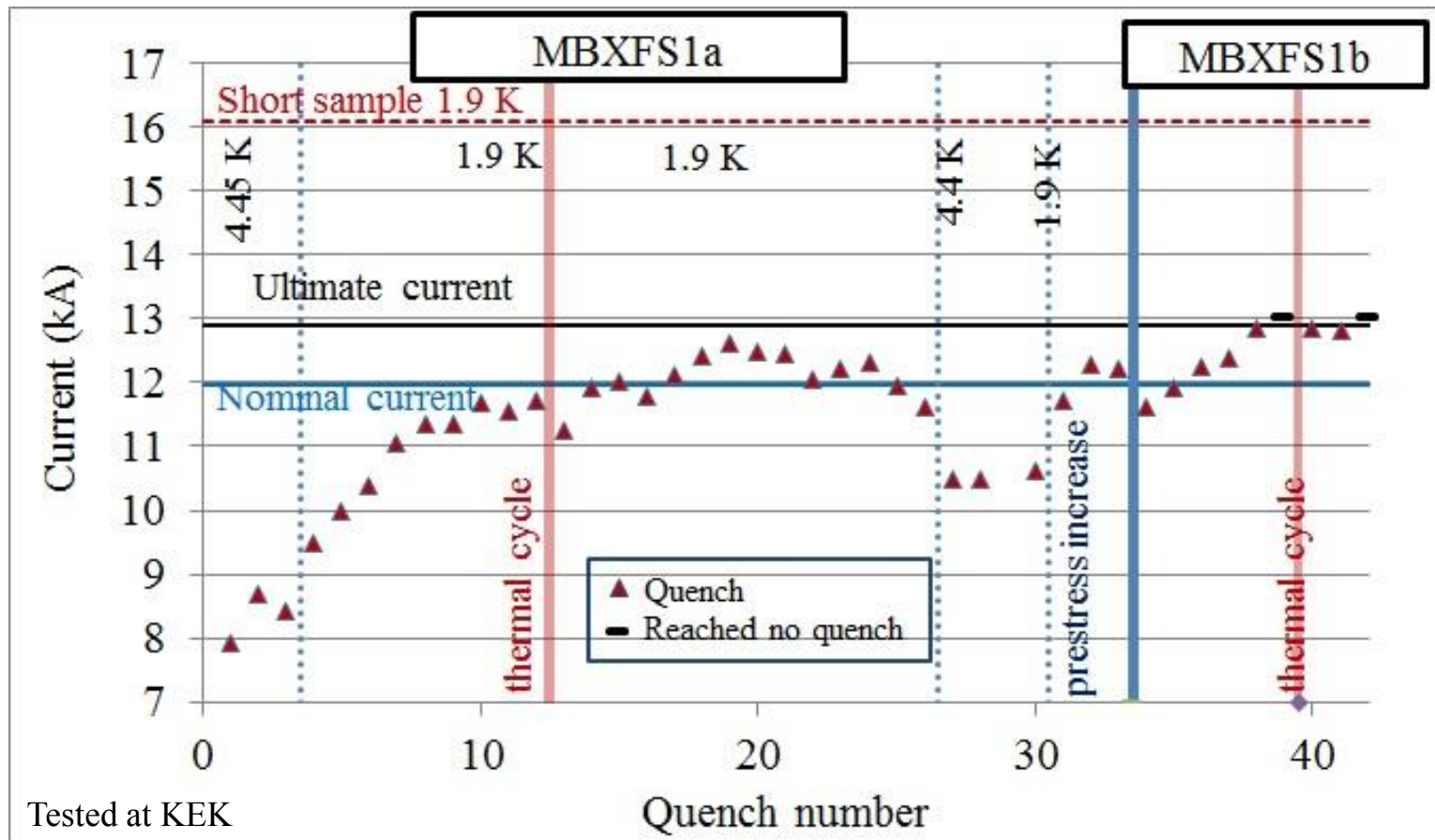
STATUS OF TESTS

- High order correctors: sextupole, octupole, decapole tested – performance reached with wide margin (see M. Statera talk)



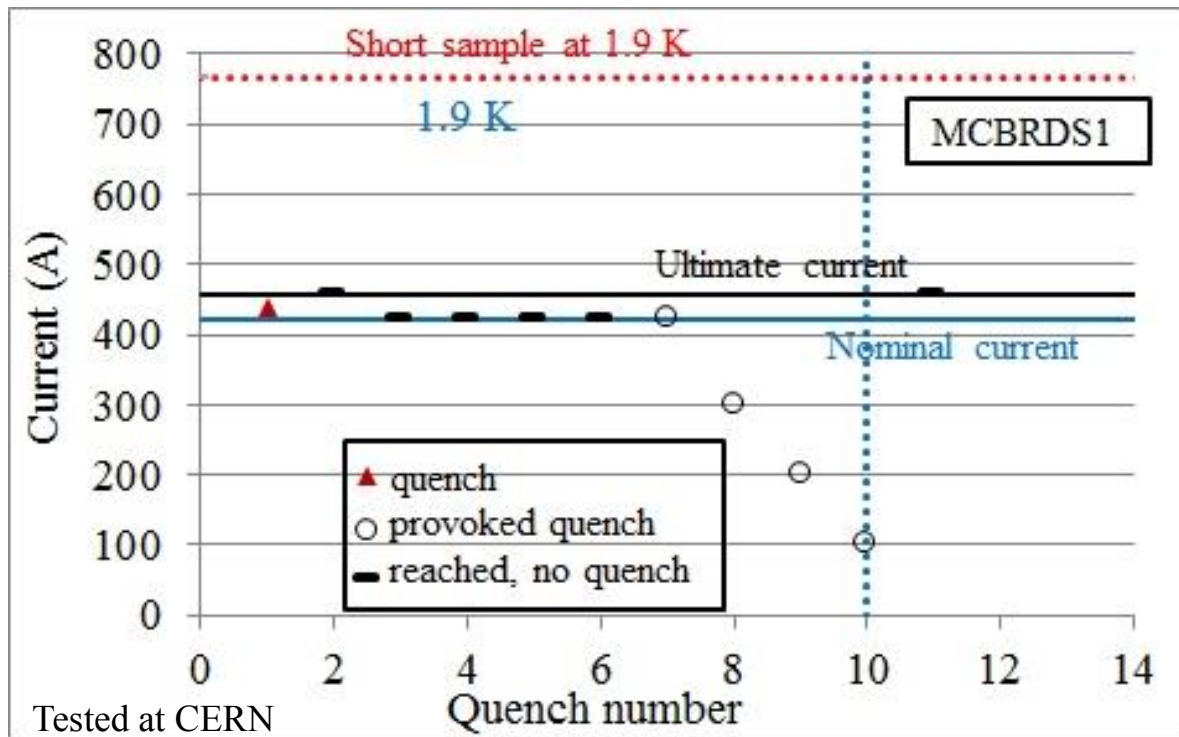
STATUS OF TESTS

- D1: one short model tested, with two assemblies – performance reached after prestress increase (see T. Nakamoto talk)



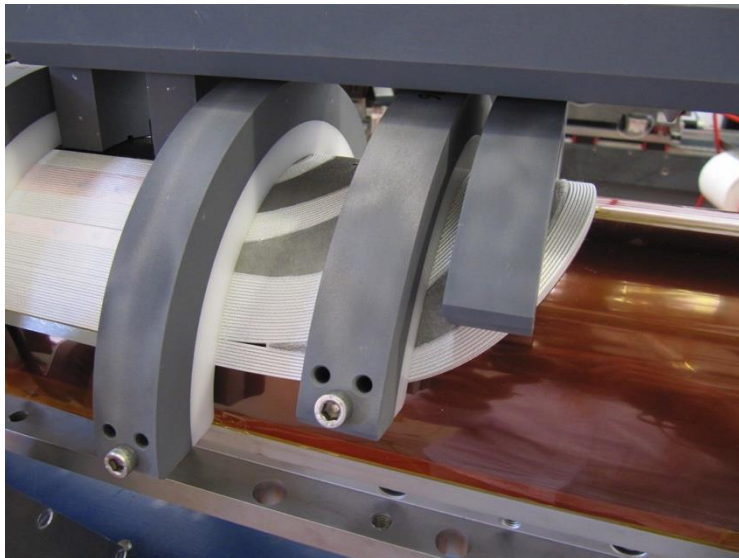
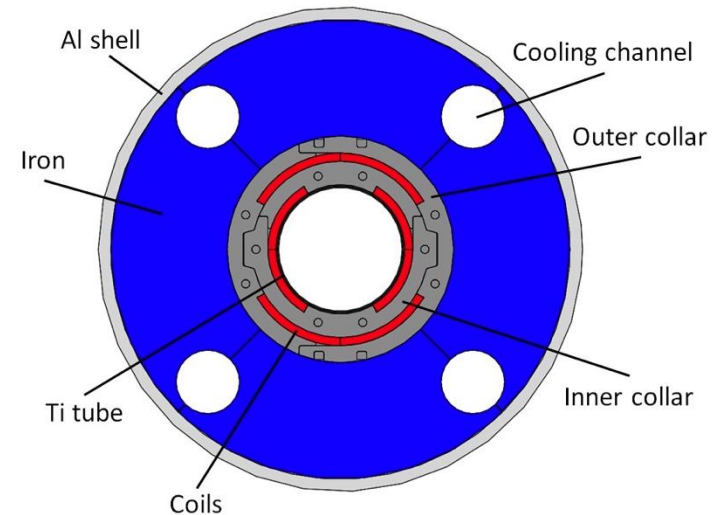
STATUS OF TESTS

- D2 corrector: short model tested, performance reached



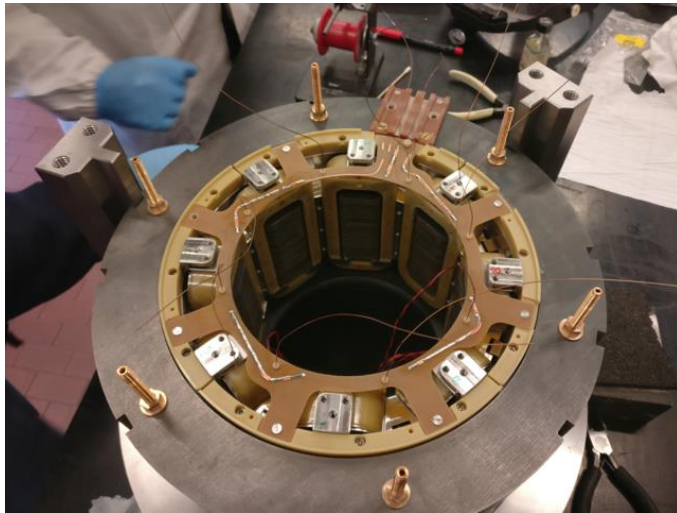
ORBIT CORRECTORS (MCBXF)

- 2.1 T in each plane, Nb-Ti
 - Rutherford cable, two layers
 - Compeley coil (talk of F. Toral)
 - Collaring test
 - First winding tests
 - Winding started!
- Collaboration agreement for series

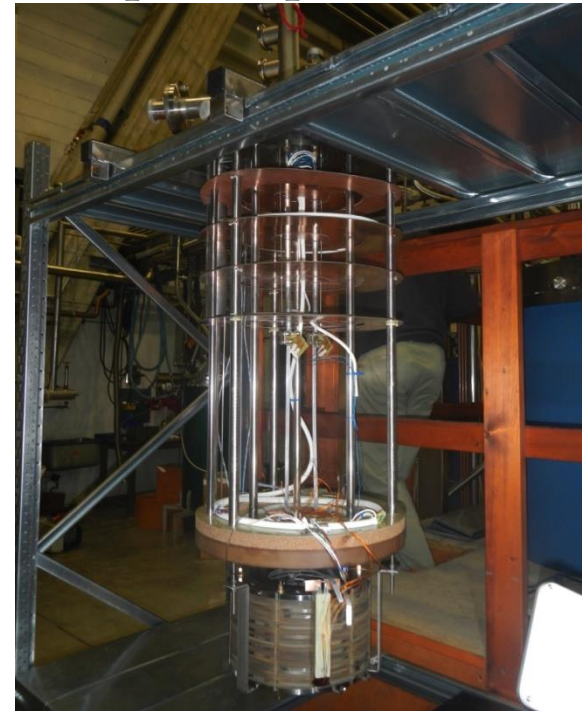


Winding of the first coil at CIEMAT (F. Toral)

- Sextupole to dodecapole, superferric design, 2-3 T peak field
 - Sextupole, octupole and decapole prototype were manufactured at LASA and tested
 - All satisfied requirements (ultimate reached) with wide margin
- Contract to manufacture dodecapole and skew quadrupole prototypes signed – delivery in 2018
- Collaboration agreement for the series



Octupole magnet (M. Statera et al.)

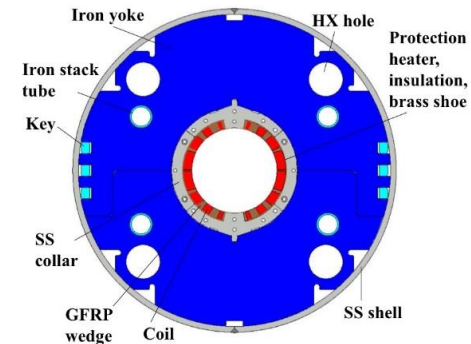


Corrector ready for test (M. Statera et al.)

E. Todesco

SEPARATION DIPOLE D1 (MBXF)

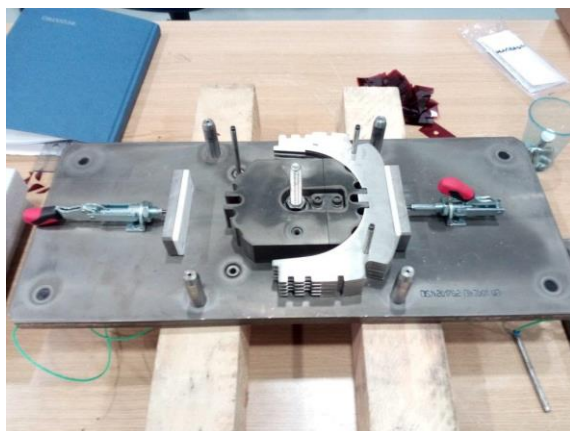
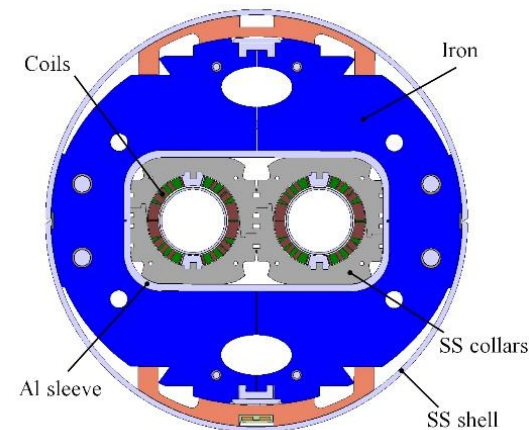
■ 5.6 T magnet (talk of T. Nakamoto)



- Short model test of second assembly – performance reached
- Two challenges:
 - Coil ends displaced towards inner bore – impregnation foreseen in the second model
 - Field quality optimization
- Second model manufacturing ongoing
 - To verify field quality and performance reproducibility - test in spring 2018
- Third model manufacturing agreed
 - To check reproducibility – test in end 2018
- Japanese contribution for prototypes and series under discussion

RECOMBINATION DIPOLE D2 (MBRD)

- 4.5 T magnet, 8 m long, double aperture (talk of P. Fabbricatore)
- Short model being manufactured in ASG
 - Acquisition of components going on, with some delays
 - Winding tests ongoing
 - Test foreseen for summer 2018

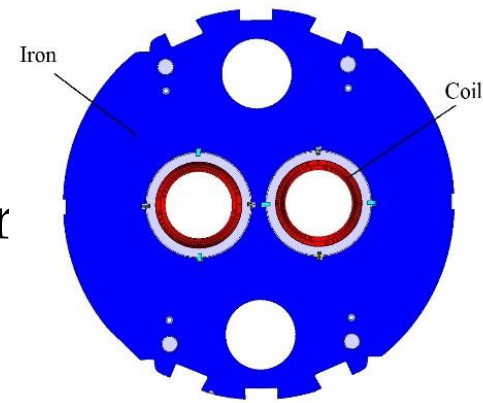


Control of collar dimension

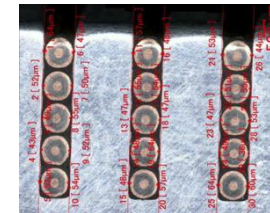
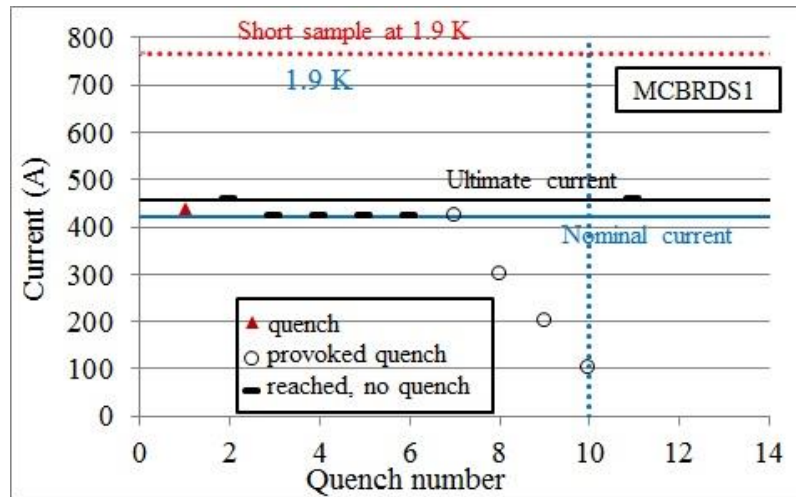
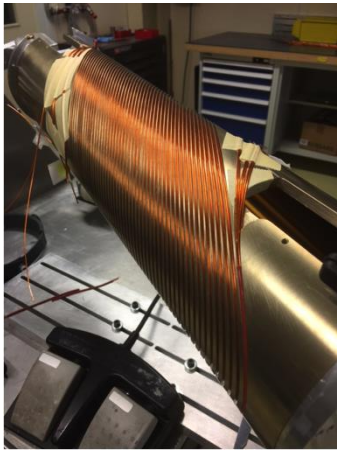


Winding tests

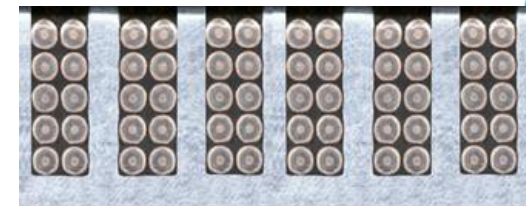
D2 CORRECTOR (MCBRD)



- We selected canted design for this corrector
- 2.6 T main field, 5 T m force, 2 m long
 - This is 13% of D1 strength – not really what one can call corrector
- We went for a 0.5 m long short model
 - 0.825 mm diameter wire, 2 wires in the same groove, 5 layers
 - Magnet reached ultimate performance – not tested above
 - Prototype construction on going



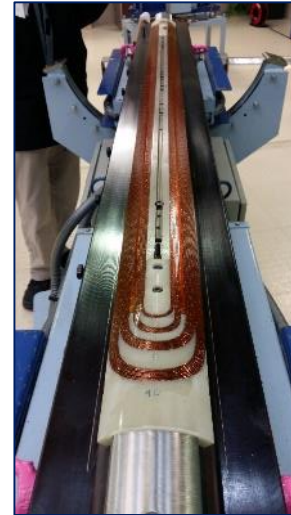
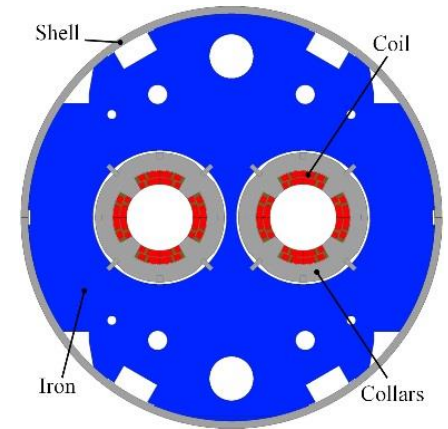
Initial design



Iteration on design

MQYY

- 90 mm aperture, two-in-one quadrupole
- Short model being built in Saclay
 - Three coils manufactured
 - Collaring at CERN
 - Test foreseen in summer 2018



MQYY coils completed in CEA (H. Felice et al.)

- QUACO initiative ongoing
 - Construction of two full length prototypes in EU industry
 - First phase (conceptual design) completed in March 2017
 - We are now in the second phase – three firms in the engineering design
 - Interesting and novative solutions being considered

CONCLUSIONS

- WP3 steers the construction of 11 types of magnets (4 mains and 7 correctors)
 - For 9.5 magnets, we rely on the contribution of 6 collaborations (US make half of the triplet)
- Today we have built and tested of 6 magnets out of 11
 - In 2018, the next 5 will be completed and tested
- All test confirm the validity of the design
- Timeline is tense, and resources are also (obviously) involved in other programs, but no showstoppers are visible today

CONCLUSIONS

- We started with paper
 - Conceptual design 2011-2014
- We moved to hardware
 - Engineering and construction of short models and prototypes 2015-2018
- We are now moving back to paper
 - Formalize acceptance criteria for series magnets, coherent documentation through the collaborations, QA/QC, test reports ...
 - With an effort to do everything possible to have the prototypes cold masses usable in the tunnel
- ... and continuing with the hardware
 - In 2018 we will have tests allowing to conclude the validation of all Nb-Ti magnet designs (MCBXF, D2, corrector quadrupole and dodecapole, MQYY)

Test summary of MBXFS1

T. Nakamoto, M. Sugano, S. Enomoto, KEK
EDMS n. 1856619

I. TEST SUMMARY

The test of the MBXFS1 magnet included the following.

- Training at 1.9 K to nominal current (12 quenches) and to 105 % of the nominal (16 quenches);
- Quenches at 4.5 K;
- A reduced program of magnetic measurements;
- Protection studies were partially performed up to 10 kA;

Ramp rate studies were not done due to time constraints. Summary of different phases is given in Table I. Test results are reported in Refs. [1]-[3].

TABLE I PHASES OF TEST AND TIME NEEDED			
Test Phase	Date	Hours	
1st cycle			
Start date	April 18, 2016	7	
End date	May 10, 2016	7	
Total time		534	
Cool-down		139	
Commissioning & quench at 4.2 K		72	
Training at 1.9 K		49	
Protection studies		0	
Magnetic measurement		31	
Warm-up		243	
2nd cycle			
Start date	May 15, 2016	7	
End date	June 13, 2016	7	
Total time		691	
Cool-down		112	
Quench at 4.2 K		133	
Training at 1.9 K		7	
Protection studies		92	
Magnetic measurement		64	
Weekend stop		48	
Warm-up		235	

II. MAGNET AND TEST FEATURES

A. General magnet features

This is the first 2-m long model magnet of the D1 built by KEK. Main parameters are given in Table II. Coil ID are given in Table III.

TABLE II MAGNET FEATURES			
Parameter	Unit	Value	
Aperture	mm	150	
Magnetic length	m	0.123	
Nominal Gradient	T/m ²	132.6	
Nominal integrated gradient	T m	0.063	
Nominal current	A	134	
Short sample current at 2.17 K	A	334	

B. Magnet features

C. Test features



Test summary of sextupole MCSXFP1

M. Statera, M. Sorbi
EDMS n. 1856594

I. TEST SUMMARY

The test of the MCSXFP1 magnet included:

- Qualification test at 2.17 K;
- Training at 4.2 K to ultimate current;
- Ramp rate tests;
- Transfer function measurement;
- Dynamic inductance measurement;
- Field quality at room temperature and at 1.9 K.

Summary of different phases is given in Table I.

TABLE I PHASES OF TEST AND TIME NEEDED			
Test phase	Date	Hours	
Start date	15.February 2016	7	
End date	26.February 2017	7	
Total time		12 h	
Cool-down		12 h	
Training		12 h	
Protection studies		12 h	
Magnetic measurements		12 h	
Warm-up		-1 wk	

II. MAGNET AND TEST FEATURES

A. General magnet features

This is the first prototype of the High Order corrector magnets; main parameters are given in Table II. Coil were manufactured at LASA with Nb-Ti 0.5 mm wire insulated by S2 (supplied by Bruker), see Table III. The magnet design went through an iteration to reduce current at 105 A; therefore this prototype cannot be installed in the LHC.

TABLE II
MAGNET FEATURES

Parameter	Unit	Value
Aperture	mm	150
Magnetic length	m	0.123
Nominal Gradient	T/m ²	132.6
Nominal integrated gradient	T m	0.063
Nominal current	A	134
Short sample current at 2.17 K	A	334



Test summary of MCBRDS1

F. J. Mangiarotti, G. Kirby
EDMS n. 1856625

I. TEST SUMMARY

The test of the MCBRDS1 magnet included (all at 1.9 K):

- Training to ultimate current;
- Ramp rate tests;
- Provoked extractions;
- Thermal cycle;
- Residual resistivity ratio (RRR) measurement;
- Splice resistance measurement;
- Inductance measurement.

A summary of different phases is given in Table I.

TABLE I PHASES OF TEST AND TIME NEEDED			
Test phase	Date	Hours	
Start date	2017/07/06	7	
Cool-down start date	2017/07/24	7	
End date	2017/08/10	7	
Total time		-35 d	
Preparation at warm		-18 d	
Cool-down		-24 h	
Training		3 h	
Inductance and splice meas.		5 h	
Ramp rate studies		2 h	
Provoked extractions		3 h	
Thermal cycle		-3.5 d	
Re-training		1 h	
Warm-up		-2.5 d	

II. MAGNET AND TEST FEATURES

A. General magnet features

This is the first model magnet of the correctors for the recombination dipoles. Its structure is based on the Canted-Cosine-Theta design. The magnet is wound with the same 0.825 mm diameter Nb-Ti wire used for the outer cable in the LHC dipoles, insulated with 55% overlapping polyamide tape. The main magnet parameters are given in Table II.

TABLE II
MAGNET FEATURES

Parameter	Unit	Value
Aperture	mm	105
Magnetic length	m	0.28
Nominal field	T	2.59
Nominal integrated field	T m	0.73
Nominal current	A	422
Short sample current at 1.9 K	A	767
Short sample current at 4.2 K	A	570
Loadline fraction at 1.9 K		55%
Strand diameter	mm	0.825
Cu/ni ₂ Cu		1.95
Number of turns per layer		109
Nominal strand current density	A/mm ²	789
Nominal superconductor current density	A/mm ²	1539
Nominal differential inductance per aperture	mH	101
Nominal stored energy per aperture	kJ	9.0

- Validation time of 10 ms.
- Voltage taps (Fig. 1)
- Two on either end of the magnet, covering the connection splice (EE1 and EE2 in the positive terminal splice, EE5 and EE6 in the negative terminal splice);
- Two covering the splice in the middle of the winding path (EE3 and EE4);
- Standard voltage taps in the station's insert;
- During cooldown EE4 stopped working; the rest were fully operational.

